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Synchronization of mother-infant feeding behavior

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ABSTRACT

In the weaning period, infants are introduced to solid food after being fed solely on milk, which involves a deliberate reorganization of the infant-caregiver feeding interaction. This multiple case study, involving 5 dyads with 10 repeated observations, analyzed its dynamical structure using Cross-Recurrence Quantification Analysis. The results showed that an optimal interaction occurs when the caregiver is leading by roughly 1–2 seconds. During the weaning period, all dyads showed signs of increased synchronization, although there are interesting differences between dyads. These findings indicate that infant-caregiver dyads co-regulate their behavior within a relatively short period.

During the first year of life, much of the infant-caregiver interaction is centered around feeding (e.g. Lindberg, Bohlin, & Hagekull, 1991; Negayama, Norimatsu, Barrat, & Bouville, 2012). In the weaning period, which generally starts around the age of 4–6 months, infants are introduced to solid food after being fed solely on milk. Because in the beginning of weaning infants are not yet capable of efficient self-feeding, parents play a prominent role in feeding (Young & Drewett, 1998). The introduction of solid food can be a challenging task (Young & Drewett, 1998). Infants have to learn how to use their oral motor and oral sensory skills for effective eating (Parkinson & Drewett, 2001), while caregivers have to follow the rapid changes in infants' oral motor and self-feeding abilities (Toyama, 2013) and have to attune to the infants' pre-verbal communication (Green, Gustafson, Irwin, Kalinowski, & Wood, 1995). Feeding problems can arise from a mismatch between infants' cues and caregivers' interpretation of these cues (Toyama, 2013, 2014; Benoit, 2009).

In the first year of life, caregiver and infant 'synchronize' their behaviors (e.g. Feldman, 2007). In a synchronous interaction, the behaviors of both partners cannot be seen as separate units; because both infant and caregiver each match their behavior to the other continuously (Fogel, 1993; Harriot & Waugh, 2002). Toyama (2013, 2014) studied infant-caregiver synchronization in feeding interactions and described spontaneous mouth opening of the infants one month after the introduction of solid food, and a peak incidence of non-fluent arm movements of the caregivers at 2–3 months, suggesting that caregiver and infant coordinate their behavior during weaning. In a previous study, we argued that the feeding interaction between caregiver and infant can be seen as a complex dynamic system (Van Dijk, Hunnius & van Geert, 2009, 2012). Such a system consists of a great number of elements that interact at different timescales (Van Geert, 2003). During feeding, infant and caregiver can also be seen as a system, with the infants' appetite, food preferences, behaviors and the caregiver's skills, concerns and goals continuously interacting and mutually influencing each other (Van Dijk et al., 2009, 2012). In this system, the constituent elements self-organize into a functional unit, a behavioral synergy for feeding interaction, typical for each individual infant-caregiver dyad. Whereas stability points to a well-coordinated behavioral synergy, in the context of feeding, variability points to an interaction in which parent and infant are still exploring (Thelen & Smith, 1993). In earlier studies, we investigated the infant-caregiver feeding interaction during the first 12 weeks of weaning and

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Table 1

Background information of the participating infants (pseudonyms) and their mothers.

	Name	Sex	Age mother (age in years)	Birth order	Seating arrangement	Birth weight (gram)	Milk type	Age (weeks) at introduction
1	“Floris”	M	37	1	All sessions high chair	4150	Breast	21
2	“Femke”	F	28	1	All sessions high chair	4050	Both	26
3	“Jens”	M	27	1	w1: baby seat, w2: on lap	3540	Both	19
4	“Lily”	F	35	3	All sessions on lap	2980	Formula	20
5	“Milou”	F	27	2	All sessions on lap	3210	Formula	22

found a decrease in day-to-day variability over a period of 6 weeks (Van Dijk et al., 2009). In a further study, we reported an increase of smooth feeding interactions (such as offering-accepting) (Van Dijk et al., 2012).

Although there are descriptions of qualitative changes in the feeding interaction, changes in the *temporal structure* of feeding are still unexplored. Complexity metrics offer the possibility to quantify the degree of coordination in terms of the structure and stability of the underlying processes (e.g. Wallot & Van Orden, 2011). These metrics result from nonlinear time-series analysis techniques, such as cross recurrence quantification analysis (CRQA). CRQA has already proven to provide valuable and unique information about parent-child interaction patterns, for instance in parent-child talk (Cox & van Dijk, 2013), in gaze coordination (Nomikou, Leonardi, Rohlfing, & Raczaszek-Leonardi, 2016) and in infant-adult vocalizations (Abney, Warlaumont, Kimbrough Oller, Wallot, & Kello, 2015). These examples illustrate that CRQA provides unique information which is also relevant for understanding the dynamics of feeding in infancy.

The research question for the current study was: What are the temporal patterns of synchrony between caregiver and infant and how do these change during the weaning period?

The study was based on the video data of the First Bites Project (collected in 2005/2006 and reported on in Van Dijk et al., 2009, 2012) which was re-coded in a very detailed manner. Because of the labor-intensive nature of coding, the current sample consisted of 5 infant-caregiver dyads who were selected based on three criteria: (a) The infant's mouth was clearly visible at all times, (b) All caregiver's arm movements (2 cm back or forth) were visible, and (c) no more than two seating arrangements were used. The dyads came from a typical population, were from middle to upper SES, and living in the Netherlands. At the start of the study, the infants were between 19 and 26 weeks of age ($M_{days} = 154.2$; $SD = 19$) and were feeding solely on milk. See Table 1 for further characteristics. Ethical guidelines of the respective universities where the original data collection took place were followed and ethical approval was gained (OUNL-U2006-219CBO).

The caretaker's behavior was coded as: a) Food scooping: caregiver gathers food with the spoon, b) Moving: caregiver moves the spoon to infant's mouth, c) Offering: caregiver offers the spoon to infant within 2 cm distance, d) Inserting: caregiver holds the spoon inside infant's mouth, e) Pulling back: caregiver retracts her arm, and f) Other: this includes all other behavior. The infant's behavior was coded as: a) Reject: infant rejects the food, b) Chewing/munching: infant's jaw is making chewing/munching movements, c) Accessible: infant's mouth is open far enough to bring at least half of the spoon into the mouth, d) Touch open: infant opens the mouth after the spoon has touched the lips, and e) Other: all other moments. See Table 2 for the coding guidelines.

The observations were originally grouped in three waves (at the introduction of solids, and 4 and 10 weeks later). Each wave consisted of five observations within a period of two weeks. Because previous studies showed that the most important changes took place between wave 1 and 2, we included only the first 10 observations in the current study. This means that the total observation period for this study covered the first 6 weeks of eating solid food.

The data was collected by researchers/research assistants who knew the families. Caregivers were instructed to feed their infant as usual. Choice of food was free, although the observations were scheduled around fruit or vegetable feedings. In the current study, we analyzed the entire feeding sessions with a duration of between 3.7 and 19.4 min each ($M = 9.9$ min, $SD = 3.9$ min).

Table 2

Guidelines for coding caregiver and infant.

Code	Name	Description
Caregiver		
F	Food scooping	Caregiver gathers food with the spoon
M	Moving	Caregiver moves the spoon with the food to infants' mouth
O	Offering	Caregiver offers the spoon to the infant
I	Inserting	Caregiver holds the spoon inside infants' mouth
P	Pulling back	Caregiver moves her arm away from infants' mouth
B	Other	All other behavior
Infant		
R	Reject	Infant rejects the offered food
C	Chewing	Infant's jaw is making chewing/munching movements
A	Accessible	Infant's mouth is open
T	Touch-open	Infant accepts the food after the spoon has touched the lips
D	Other	All other behavior

Note: high chair and baby seat feeding was face to face, feeding on lap was with a roughly 90-degree angle.

Caregiver	Infant				
	Other	Chewing	Reject	Touch-open	Accessible
Food Scooping					
Moving					
Offering		Feeding Mismatch		Feeding Match	
Inserting					
Pulling back				Feeding Mismatch	
Other					

Fig. 1. State space or ‘behavioral matrix’ of the feeding interaction, presenting the two possible ‘matches’ of behavioral categories distinguished in this study: Feeding Match (grey) and Feeding Mismatch (black).

The observations were coded using MediaCoder (Bos & Steenbeek, 2006), a freely available observation software program. Reliability was based on 12% of the videos that were double coded (blind) by the researcher and a trained PhD student. The codes were transformed into time series, a percentage of agreement was calculated for each window of 1.5 s, and its significance was tested with a Monte Carlo test. On average, the percentage of agreement for the caregiver was 77.4% ($\kappa = .73$, $p < 0.01$), and 84.3% ($\kappa = .80$, $p < 0.01$) for the infant.

CRQA was used to quantify the synchronization of infant-caregiver interactions (e.g. Marwan & Kurths, 2004; Zbilut, Giuliani, & Webber Jr, 1998, Cox & van Dijk, 2013). Since in the current study, the caregivers’ and infants’ behaviors were coded with different behavioral categories, we used a cross-matching procedure called *Chromatic* CRQA (Cox, van der Steen, Guevara Guerrero, Hoekstra & van Dijk, 2016).

Fig. 1 shows the state space, or the ‘behavioral matrix’ of the feeding interaction and the two different kinds of behavioral matches that were defined. ‘Feeding Match’ indicates behavioral matches that contribute to a positive feeding interaction, whereas ‘Feeding Mismatch’ indicates behavioral mismatches between the caregiver and the infant which may lead to a negative feeding interaction. As can be observed, four combinations of behavioral categories are defined as ‘Feeding Match’. Eight combinations of behavioral categories are defined as ‘Feeding Mismatch’. The remaining combinations of behavioral categories were not of interest for the purpose of the analyses.

The behavioral matrix is used as the starting point for the construction of the *Cross-Recurrence Plot* (CRP), which is a plot with the infant’s time series along the horizontal axis, and the caregiver’s time series along the vertical axis. All ‘matching points’ are depicted as colored dots (Fig. 2); black dots for the recurrent Feeding Mismatches, grey dots for the recurrent Feeding Matches. The thick black line in Fig. 2, indicates the *Line of Synchrony* (LOS), which represents all recurrent points without a delay. All other dots represent matches or mismatches between caregiver and infant with a particular time lag between them. More specific, all dots above the LOS represent moments where the infant precedes the caregiver with his/her actions and all dots below the LOS represent moments when the caregiver precedes the infant.

Several measures can be derived from the spatial layout of the black and grey dots. In this study, we used the *Recurrence Rate* (RR) which quantifies the proportion of Feeding Matches or Feeding Mismatches across all possible time scales (with a sample rate of 0.5 Hz). RR_{Match} reflects the relative contribution of Feeding Matches to the overall coordination, whereas $RR_{Mismatch}$ reflects the relative contribution of Feeding Mismatches to the overall coordination.

Fig. 2. Illustration of a Chromatic Cross-recurrence plot (CRP) produced with the cross-matching procedure (Floris, session 1). Measures derived for the LOS profiles are based on the distributions of grey dots (Matches) and black dots (Mismatches).

Fig. 3. Example of Diagonal Cross-Recurrence Profile for both matches (left) and mismatches (right).

For this study, Diagonal Cross-Recurrence Profiles (DCRPs or LOS-profiles) were constructed to investigate the temporal coordination around the LOS, one for the Feeding Matches, the other for the Feeding Mismatches (see Fig. 3 for examples). A DCRP displays the recurrence rate on the vertical axis, for 30 s around the LOS (from -15 s to 15 s). The middle of the horizontal axis (0 s delay) represents the RR on the LOS.

The main measure for the DCRP is the peak in the recurrence rate curve and its location, defined as the highest absolute RR value deviating at least 2 standard deviations from the profile's average RR, with its location on the horizontal axis (delay). The value for the delay in seconds is indicated with τ . A positive τ refers to a temporal delay for the infant (i.e. the caregiver is leading in time), whereas a negative τ indicates a temporal delay for the caregiver (i.e. the infant is leading in time). This results in RR_{Match} , with the corresponding delay called τ_{match} for the Feeding Matches. For the Feeding Mismatches, we identified a negative peak, called $RR_{Mismatch}$, with the corresponding delay $\tau_{Mismatch}$. Feeding synchrony was operationalized with two indicators: 1) the RR value of the peak (higher absolute RR corresponds to a higher degree of synchronization) and, 2) the τ value (closer to zero corresponds to closer temporal attunement; its sign indicates who leads and who follows). We constructed the DCRPs for each individual dyad, for Feeding Matches and Feeding Mismatches. Subsequently, we tested whether the indicators (RR_{Match} , $RR_{Mismatch}$, τ_{Match} , $\tau_{Mismatch}$) were different between waves with Monte Carlo permutation tests (e.g. Todman & Dugard, 2001) for each dyad. We used 5000 permutations per two-tailed MC-test ($\alpha = .05$).

Fig. 4 shows the average DCRPs for Feeding Matches for both waves for each dyad separately. As can be observed, most profiles show a peak close to the LOS, with the exception for wave 1 for both Floris and Femke. These indicators also display clear inter-session differences when inspecting the standard deviation of τ_{match} (see Table 3), at least more than the other dyads. The profiles of Jens, Lily and Milou look rather similar: they show a slight 'dip' right before the LOS, and a prominent peak right after the LOS, for almost all sessions.

Fig. 5 shows the DCRP Feeding Mismatch for all dyads. Here, all dyads show a negative peak shortly after the LOS. Some of Floris' and Femke's sessions do not show the typical pattern.

Comparing the values between the first and the second wave for the Matches, three dyads (Floris, Lily, and Milou) show a

Fig. 4. Average LOS Profiles for interaction Matches of wave 1 (grey line) and wave 2 (black line) for each of the dyads.

Table 3

Overview of the mean DCRP for the Feeding Matches measures for series 1 and series 2 and the p-value for their difference score.

Dyad	RR _{match}			τ_{match}		
	M1 (SD)	M2 (SD)	p-value M1/M2	M1 (SD)	M2 (SD)	p-value M1/M2
Floris	1.426 (.11)	1.801 (.19)	.003*	14 (8.15)	1.2 (.84)	< .001*
Femke	1.510 (.22)	1.506 (.13)	.501	−10.6 (13.01)	0.8 (1.64)	.905
Jens	1.556 (.14)	1.407 (.14)	.057	2 (.71)	0.6 (.55)	< .001*
Lily	1.322 (.07)	1.668 (.17)	< .001*	2.8 (.84)	2.6 (1.95)	.627
Milou	1.249 (.06)	1.468 (.13)	.006*	1 (0)	1 (0)	> .999

Fig. 5. Average LOS Profiles for interaction Mismatches for wave 1 (grey line) and wave 2 (black line) for each of the dyads.

significant positive trend in RR_{Match} (see Table 3). In addition, two dyads (Floris and Jens) became more closely synchronized in time concerning their matching feeding behaviors, as indicated by τ_{Match} . Milou and her mother were immediately closely synchronized, as their τ -values indicate. There seems to be a negative trend in $RR_{Mismatch}$ in 4 dyads, but the difference between the waves is only significant for Floris (see Table 4). There is also a negative trend for $\tau_{Mismatch}$, meaning that the peak gets closer to the LOS in the second wave of observation, which is significant in three cases (Femke, Jens, and Milou).

In sum, the results show that in three dyads the peak of the RR of the Feeding Matches becomes higher over time. In two further dyads, this peak gets closer to the LOS, implying a closer temporal attunement. For Feeding Mismatches, negative peak of RR becomes deeper over time for one dyad, whereas in three dyads the negative peak gets closer to the LOS. All dyads show at least one indicator of increased synchronization, but the way in which they synchronize differs. However, it should be noted that all significant differences were in the same direction, and that none of the dyads showed a decrease of synchronization over time.

This study described the development of the critical transition in infant-caregiver feeding interactions during weaning. The process was studied ‘as a whole’ by looking at the dynamical organization of the coupled behaviors of caregiver and infant. The results showed that for all dyads, optimal coordination occurred when the caregiver led the infant by roughly 0–2 seconds, or in other words when the infant followed the caregiver by 0–2 seconds delay. This leads to the question as to who controls the feeding. According to Toyama (2014), caregivers play a crucial role right after the introduction of solid food, because infants do not have self-feeding skills yet. However, infants are not passive recipients of the caregiver, but anticipate and follow closely. In the context of

Table 4

Overview of the mean DCRP for the Feeding Mismatches measures for series 1 and series 2 and the p-value for their difference score.

Dyad	RR _{Mismatch}			$T_{Mismatch}$		
	M1 (SD)	M2 (SD)	p-value M1/M2	M1 (SD)	M2 (SD)	p-value M1/M2
Floris	0.758 (.19)	0.391 (.07)	.006*	10.80 (11.43)	0.6 (.55)	.111
Femke	0.789 (.15)	0.641 (.20)	.133	5.4 (7.77)	0.4 (.55)	.011*
Jens	0.548 (.11)	0.595 (.12)	.735	0.8 (.45)	0 (0)	< .001*
Lily	0.541 (.07)	0.540 (.15)	.488	1.4 (.55)	2.2 (2.28)	.385
Milou	0.450 (.13)	0.358 (.10)	.122	0.2 (.45)	0 (0)	< .001*

breastfeeding, Young and Drewett (1998) have argued that although a mother may be in control because she initiates feeding, the infant has many possibilities for control *during* feeding. Although a mother seems to be controlling (breast)feeding, she may actually respond to subtle cues from the infant. It may be the case that also during weaning the caregiver is responding to subtle cues of the infant, which were not detected by our coding scheme. The mere fact that one actor is a few seconds ahead of a second actor does not necessarily mean that the first is actually leading the interaction. For instance, Stepp and Turvey (2010) have demonstrated that such a pattern may also occur from strong anticipation in complex adaptive systems. It is possible that the type of synchronization observed here results from a similar dynamical mechanism involving anticipatory perception-action coupling between caregiver and infant. Applied to our study, it means that though we have observed that optimal feeding occurs when the caregiver is leading in time by approximately 1–2 seconds, this does not mean that the caregiver controls the feeding interaction. It could also mean that the caregiver coordinated her behavior to the ‘anticipated’ actions of the infant, resulting in optimal feeding dynamics.

With regard to developmental changes, caregiver and infant became more closely synchronized in the first 6 weeks of weaning, at least in one respect. This reflects more coordinated interaction and an increased co-regulation of consensual frames (see Fogel, 1993). The decrease in time lag represents closer attunement to each other’s behavior which facilitates a quicker response (Feldman, Greenbaum, & Yirmiya, 1999; Feldman, 2007). In this study, we have observed clear inter-individual differences, which are characteristic of infant feeding and eating behavior (Young & Drewett, 2000). Whereas Milou and her mother were immediately closely synchronized in time, which suggested that there was almost no perturbation, other dyads (Floris, Jens, and Femke) needed some time to become synchronized. Also, for the dyad of Femke, the timing of matching behaviors seemed to stay variable until the end of the six-week period. The results therefore may suggest that Femke and her mother were still exploring how to synchronize their matching feeding behaviors. Earlier analyses (reported in Van Dijk et al., 2012) also indicated that Femke was a slow eater and showed relatively much food refusal even at 12 weeks after the introduction of solids. Although we have no information about Femke’s later development, we may hypothesize that their lack of forming a pattern could be characteristic of poor co-regulation during feeding. The main limitation of this study was the small sample size. As a consequence, the current results are indications of possible effects which need further investigation. In addition, the participating children were all fed by their biological mothers and the results may not be representative for other feeding relationships. Future research requires more participants, and should include both mothers and fathers. Another limitation of this study is the inter-coder reliability. Cohen’s kappa was 0.73 for the caregiver and 0.80 for the infant –which is ‘substantial’ but not ‘almost perfect’ – even after extensive training. This was probably due to the subtleties of the behaviors that were coded and the fact that the videos were made in naturalistic circumstances.

Further research is needed in order to test the current results more rigorously to improve our understanding of the underlying mechanism and causality, and in order to be able to generalize these results to a broader context.

Contributions

MvD designed the study and collected the video data (both with S. Hunnius and P. van Geert in 2005/2006). She also developed the current research question, supervised BvV and revised the thesis into this article.

BvV developed the refined coding scheme, coded all data, performed the Monte Carlo analyses and wrote a first version of the manuscript as her research master thesis.

RC designed the analysis, conducted the RQA, interpreted the results and revised the manuscript

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